Report for 2002IL1B: Multi-Objective Decision Support Tools for Protection of Streams in Urbanizing Watersheds

- Conference Proceedings:
  - Allred, K.O., J.W. Nicklow, M.K. Muleta, L.A. Duram, 2003, A multiobjective SDSS for management of urbanizing watersheds: The case of the Lower kaskaskia Basin, Illinois, in Proceedings of the 2003 EWRI Congress, ASCE, Reston, VA.
  - Nicklow, J.W., M.K. Muleta, 2002, Integrative decision making for watershed management using evolutionary algorithms, in Porceedings of the 2002 EWRI Congress, ASCE, Reston, VA.

Report Follows:

Illinois Water Resources Center
Annual Report

1. **Project Number:** 2002IL1B
2. **Project Title and PIs:** Multi-Objective Decision Support Tools for Protection of Streams in Urbanizing Watersheds; Dr. John W. Nicklow, Asst. Professor of Civil Engineering, and Dr. Leslie A. Duram, Assoc. Professor of Geography, Southern Illinois University at Carbondale
3. **Research Category:** Land Management, Urbanization, Decision Support System
4. **Problem and Research Objectives:** The 20th century has witnessed the conversion of many natural and agriculturally dominated watersheds to urban developments. The Lower Kaskaskia watershed, located in southwestern Illinois, is an example of a basin that is undergoing extensive land use changes through urbanization. It is clear that such drastic landscape changes in this and other watersheds stimulate a corresponding cascade of downstream adjustments in water quantity and quality. Sophisticated simulation models and Geographic Information Systems (GIS) have become the standard means for assessing the impacts of urban sprawl on water resources systems. Simulation and GIS models alone, however, are incapable of directly revealing optimal land development patterns that meet specified objectives. More comprehensive watershed-scale modeling techniques are needed to overcome this limitation and assist decision makers in planning new developments. Therefore, the objectives of this study were (i) to develop a basin-wide decision support model that could be used as a guide by land use managers and watershed management institutions to identify optimal land use changes in the Lower Kaskaskia and other similar watersheds; and (ii) investigate stakeholder concerns and reactions regarding formulation and application of the model in order to ensure local support and utility. Outcomes of this two-year project include the decision support model; a historical survey and conceptual model of the relationship between urbanization and the hydrologic and water quality variability in the Lower Kaskaskia basin; results of the decision support model when applied to the basin; and a summary and set of conclusions concerning the social science investigation.
5. **Methodology:** The decision support model has been created by integrating the U.S. Department of Agriculture's Soil and Water Assessment Tool (SWAT) for comprehensive hydrologic simulation, a GIS for generating input and visualizing output, and an evolutionary optimization algorithm for identifying weighted, optimal land use patterns. The combination of these modules results in a single, multi-objective decision framework capable of yielding land use changes that solve the following problem: Minimize the adverse effects on water quality and quantity caused by urbanization, while maximizing economic growth and profit to be earned through development; subject to laws governing watershed hydrology and realistic bound constraints on feasible land development. Within this problem formulation, scaled weighting factors are assigned to each of the two individual objectives so that the user can convey his or her personal hierarchy of specified objectives to the decision model. The independent decision matrix is comprised of alternative landscapes, while dependent variables are those that describe water quantity and quality variability and economic growth. By using SWAT to solve constraints related to watershed hydrology, the complex interactions between land use changes and water quality and quantity are fully captured. The remaining constraint that allows only feasible land use changes is handled directly by the optimization algorithm. Two types of evolutionary algorithms, a genetic algorithm (GA) and

an artificial life algorithm (ALA), have been investigated for solution to this problem. The GA is found to be particularly capable, while minor issues related to the ALA are still being resolved. The optimal landscape is defined as that which minimizes sediment yield, phosphorus and nitrogen loads, and other water quality indicators in subsequent streams, while simultaneously maximizing anticipated profit from urban development. Profit due to urbanization has been defined through distance relationships; lands closer to the Metro East region or in the vicinity of major interstates are more likely to incur larger profits from urbanization. In addition, following an extensive review of watershed planning activities in the Lower Kaskaskia basin, key stakeholders were identified. Meetings with stakeholders were used to promote technology transfer and to illuminate concerns and recommendations regarding this multi-objective planning effort and the value of model parameters.

6. **Principal Findings and Significance:** Detailed findings and conclusions will be presented in a forthcoming Master's thesis, which will represent the final report for this project, and in a manuscript to be submitted to a peer-reviewed journal. Briefly, findings thus far can be categorized into the quantitative modeling component and social science aspect of the research. The historical evaluation of existing data does reveal a relationship between increasing urbanization and negative impacts to hydrology and water quality. That relationship, however, is quite variable and difficult to quantify. Results of the decision support model for the Lower Kaskaskia basin indicate that the integrative approach can effectively identify areas in which development should occur from water quality and economic perspectives. The method thus serves as a guide for planning activities in urbanizing basins, with the understanding that modeling results cannot entirely replace the qualitative decision making aspect of watershed management. The latter refers to varying political and social dynamics and one's own personal hierarchy of management objectives that may not be quantifiable or that may not be integrated into the model.

   The social science objectives were realized through several important stages. First, an extensive investigation of stakeholder involvement identified two primary environmental planning and management activities in the Lower Kaskaskia basin: The Kaskaskia River Corridor Stewardship Plan, which brought stakeholders together to form the Kaskaskia River Private Lands Initiative Committee; and the Metro East Sustainable Growth Resource Group, which is comprised of a broad range of stakeholders and has been recently active as part of the Illinois Growth Task Force. The investigation also revealed the pivotal role played by the Southwest Resource Conservation and Development (SWRC&D) office in coordination of land management efforts in the area. Second, on July 22, 2002, the research team met with the Director of the SWRC&D. This was a valuable meeting in which early findings from the model were presented and relevant stakeholder groups were discussed. Third, on November 15, 2002, the team convened a broadly represented focus group meeting of fifteen stakeholders in Mascoutah, Illinois. Participants represented the Cities of Belleville, Swansea, and Shiloh, Madison County, SIMAPC, IDNR-C2000, USACE, Trust for Public Lands, American Bottom Conservancy, Sierra Club, and SWRC&D. The format of the meeting included a brief presentation of the model, followed by questions and discussion.

   Generally, stakeholders found the model interesting and potentially useful as a guide in planning activities. The meeting led to a great deal of feedback, including comments about application limitations, model cost and convenience, and data requirements. The group identified a number of parameters that should be integrated into the model. It was clear, however, that while some suggestions were realistic, many would be nearly impossible to quantitatively define within the modeling effort. Some participants also conveyed the notion that issues of regional planning are always secondary to other local concerns, which is indicative of the complexity revolving around the numerous perspectives that should be represented in broad planning activities. In addition to these findings, several general points became clear: (i) Stakeholders have a difficult time conceptualizing a model at the watershed level; rather they demand a sub-watershed scale for management. This finding makes it difficult to implement broad planning activities that promote watershed-scale ecosystem health. (ii) Although attempts were made to focus group discussion on model improvements and recommendations, it was difficult to move 'entrenched' opinions beyond their narrow views of the topics. Specifically, two environmentalists firmly felt their topic (e.g., aesthetic values of habitats) should be included in the model, yet no one could identify data to represent these variables. Consequently, much of the discussion revolved around tangential comments. (iii) Stakeholders are concerned about whether the model will be available to them from the perspective of cost, time, and computing capabilities. Emphasis was placed on the need for a user-friendly, low-cost model that runs on a simple personal computer. (iv) Stakeholders believe that it would be helpful to focus on specific types of development in the model's findings. For example, the model could help determine whether some areas are better for residential versus industrial development. Finally, it became clear that many delicate preceding relationships existed among various stakeholders in the watershed. Research had to move carefully through that existing framework, so as not to inflame past conflicts, and future planning efforts in the region must be sensitive to these somewhat concealed relationships and historical issues.

7. **Graduate Students Supported with Funding:** Mr. Kyle Allred, M.S., Dept. of Civil Engineering, College of Engineering, SIUC, August 2, 2003 (expected); Dr. Misgana Muleta, Ph.D., Dept. of Civil Engineering, College of Engineering, SIUC, May 10, 2003.

8. **Publications and Presentations**

   Allred, K.O., J.W. Nicklow, M.K. Muleta, L.A. Duram, 2003, A multiobjective SDSS for management of urbanizing watersheds: The case of the Lower Kaskaskia Basin, Illinois, in Proceedings of the 2003 EWRI Congress, ASCE, Reston, VA.

   Nicklow, J.W., M.K. Muleta, 2002, Integrative decision making for watershed management using evolutionary algorithms, in Proceedings of the 2002 EWRI Congress, ASCE, Reston, VA.

9. **Notable Achievements:** The strategic interface between an optimization algorithm and a comprehensive watershed simulation model represents a new methodology and visualization tool to guide cost effective and environmentally sound watershed planning decisions. In addition, new insight regarding the social dynamics of the Lower Kaskaskia have been revealed, which will likely serve as key information in future planning activities.

10. **Related and Seed Projects**

    Beaulieu J., J. Nicklow, S. Kraft, C. Lant, 2001, Decision support for water quality planning in multiple ownership watersheds: The case of the Cache River and applications in other Illinois watersheds, Illinois Council for Food and Agricultural Research: Water Quality Strategic Research Initiative. 7/01-6/03, $113,000.

    Nicklow, J.W., 2001, A management model for controlling hydrologic alteration in the Illinois River, The Nature Conservancy, Freshwater Initiative. 1/02-6/03, $15,000.